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RESEARCH DEPARTMENT

The Suppressed Frame System of Telerecording

Report No. T.052
[1955/2]

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

THE SUPPRESSED FRAME SYSTEM OF TELERECORDING

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Report No. T.052
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THE SUPPRESSED FRAME SYSTEM OF TELERECORDING

PART I: THE RECORDING EQUIPMENT[1]

1. INTRODUCTION.

This part summarises the fundamental and practical aspects of a suppressed-frame 35 mm telerecording machine designed and constructed by Research Department in order to provide an additional telerecording channel for use in connection with the Coronation.

In view of the comparatively short time which was available for the design and construction of this channel, it was decided that any method of recording which required the development of new mechanisms and optics should be avoided. Tests were therefore made in order to determine the picture quality which could be obtained using a high grade television monitor[2] and commercially-available 35 mm cine camera. The results of the tests indicated that the construction of an apparatus of this type would be amply justified.

2. FUNDAMENTAL CONSIDERATIONS.

2.1. The Recording Cycle.

The need to use a standard film-transport mechanism restricted the choice of system to one employing an intermittent-motion camera, since previous investigations had shown that any attempt to use flying-spot or other continuous-motion systems would require a longer period of development. Rapid-pulldown cameras are not available for 35 mm film, and the choice was therefore further restricted to cameras having a pulldown angle of between 140° and 180°.

This meant that the recording cycle* would consist of exposure during one whole television frame while the film was stationary in the gate and pulldown of the film during the next (suppressed) television frame.

2.2. Vertical Resolution.

The obvious disadvantage of such a system of telerecording is that each frame of film will contain only half the detail of the television picture, that is to say, only 202½ of the original 405 lines would be recorded, and this loss was at first regarded as likely to be intolerable. The examination of a large variety of telerecordings made specifically for the purpose of testing this belief showed, however, that the loss of vertical resolution was in fact by no means unacceptable, indicating that the eye takes cognisance of the considerable correlation existing between adjacent lines of the average television picture. The effects of correlation between adjacent lines of a television picture may be described by consideration of extreme cases. If the television picture consisted solely of vertical bars, all lines would carry identical information and the picture would be faithfully reproduced with only a single scanning line broadened to fill the whole height of the frame. If, however, the pattern of bars falls horizontally in the picture, and the number of bars is greater than the number of scanning lines, that pattern can never be faithfully reproduced. The normal television picture will fall statistically between these limits. Whereas at least 405 lines are essential to provide a sufficiently smooth background (line structure) to the television picture, it is found that a 202½ line picture nearly always provides sufficient vertical resolution. Whilst it would not be suggested that a picture having 202½ line resolution is indistinguishable from one having 405 lines, the use of spot wobble to broaden the lines in a suppressed-frame recording is found to give an acceptable picture when the film is re-scanned by 405 lines in the telecine machine. By this means original line structure is, of course, restored, although pairs of lines may carry identical information.

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*Method proposed by P.H. Dorté in 1947

Any lack of correlation between adjacent lines is most noticeable when reproducing a high-contrast low-angle edge. The attempt to portray such an edge with broadened lines results in a series of serrations of steps which may be obvious from time to time to the experienced observer, but it is doubtful whether this defect is noticeable to the public.

2.3. Spot Wobble and Noise.

The obliteration of the line structure by carefully adjusted spot wobble is of course essential in any telerecording system if beat patterns are to be avoided when the film is rescanned.

Where the number of lines recorded on the film is less than the number employed in the rescanning process, it follows that some adjacent lines in the reproduced picture will contain identical signal information and also identical recorded noise. In the case of the suppressed-frame system each recorded line will, in theory, be reproduced twice so that there is now a simple addition of the noise on adjacent lines whereas in the original picture the noise on adjacent lines was unrelated. This has the effect of reducing the signal-to-noise ratio by about 3 dB.

2.4. Movement Portrayal.

There is only one other fundamental difference between the suppressed-frame and other current methods of telerecording. This is that each frame of film produced by the suppressed-frame system contains only one image of any moving object. The implications of this are discussed in Research Department Report No. T.041.

2.5. Sound Recording.

In common with other telerecording channels, the suppressed-frame equipment employs a combined camera to record both picture and sound on the same negative, which, of course, greatly facilitates editing and reduces film-stock and processing costs.

The desired film processing required for the picture is not the most suitable for sound recording, but the latest design of sound recording apparatus when used under conditions dictated entirely by the requirements of the picture, nevertheless gives a most satisfactory result.

3. DESCRIPTION OF THE RECORDING MACHINE.

3.1. General Description.

It is not proposed to describe details of the individual units, since these are fully explained in the Research Department Handbook, entitled "Experimental Suppressed Frame Television Recording Channel", and the following descriptions are limited to considerations influencing the design.

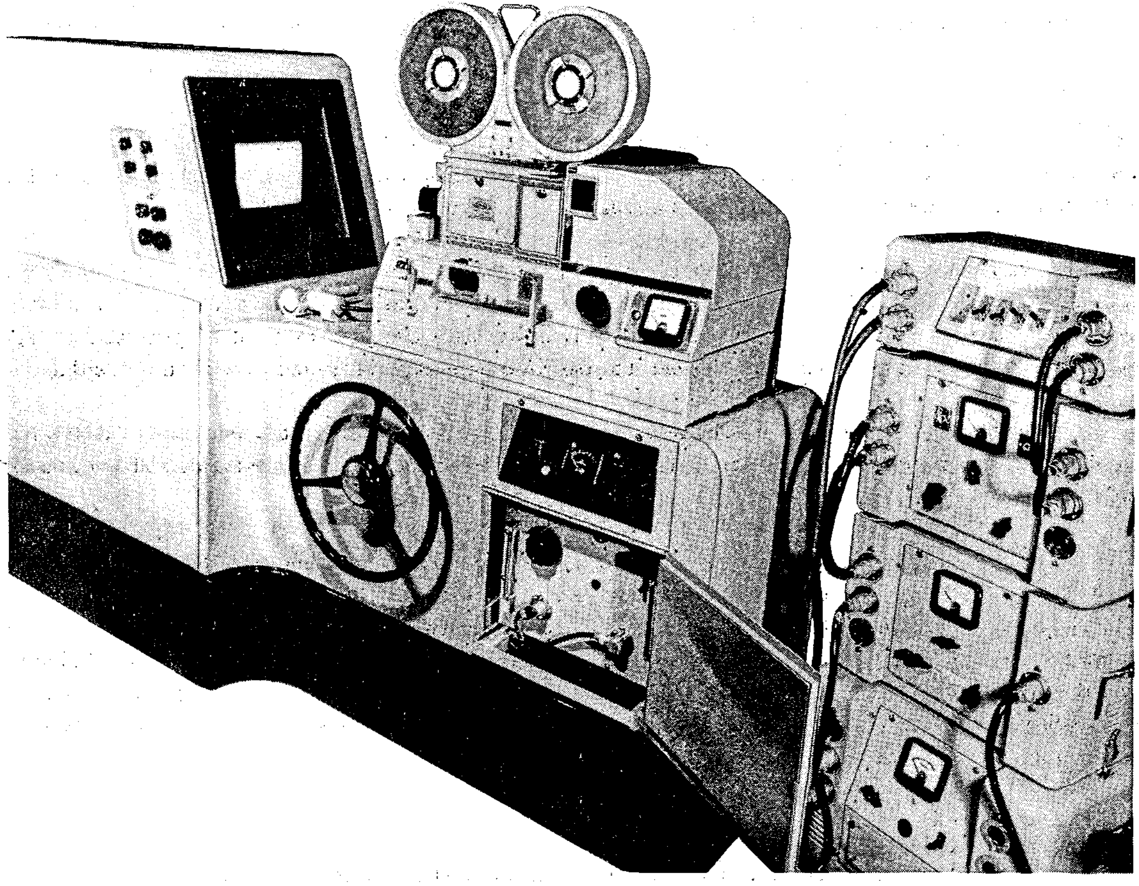

Fig. 1 - Suppressed frame television recording assembly

The complete installation comprises:

a. Two machines, of which one is illustrated in Fig. 1. One machine is reloaded whilst the other is in operation.

b. A picture-control desk to permit monitoring and adjustment of levels during the recording.

c. A video-control bay containing apparatus for the correction of the frequency and amplitude characteristics of the signal.

d. A sound-control bay giving monitoring, adjustment and distribution facilities.

e. Two sound amplifier stacks associated with the recording galvanometers.

The picture display portion of the machine, illustrated in Fig. 1, is based upon a Research Department picture monitor[2], while the portion of the machine on the right-hand side of the illustration consists of the combined picture and sound camera, the base containing the control equipment and camera-phasing apparatus.

3.2. The Picture Display.

The cathode-ray tube employed is a 12 in. Cintel B302C/X1, which has a short persistence zinc sulphide phosphor emitting blue light (450 mμ) and a high-resolution electron gun. The diagonal of the raster on the tube face is 10 in.

Video amplifier and timebase circuits are of orthodox design, but great care has been taken to realise a high standard of performance. The deflector coils are toroidally wound and the focus coil is of special design with an adjustable gap. Pincushion correction coils are fitted to improve the rectilinearity of the display.

With 14 kV anode potential on the cathode-ray tube, it was found that with a peak beam current of 40 μA the spot size achieved caused no measurable loss of resolution of 3 Mc/s bars.

An additional unit provides a blanking pulse to black out the tube during the pulldown of the camera, and therefore no mechanical shutter is necessary. The control pulse for the blackout unit is generated in the camera, so that when the camera is running only alternate frames are displayed by the monitor. To facilitate correct amplitude adjustment of the 10 Mc/s spot wobble without running the camera, the blackout circuit can be switched to operation by a binary counter actuated by frame synchronising pulses.

3.3. Camera Phasing Arrangements.

In order to maintain the correct phase relationship between the pulldown of the film and blackout of the monitor, it is necessary that the blackout trigger pulse should be generated by a device mechanically coupled to the camera which will allow the duration of the exposure of each film frame to be made precisely equal to the period of one television frame, and to commence and finish simultaneously with the television frame.

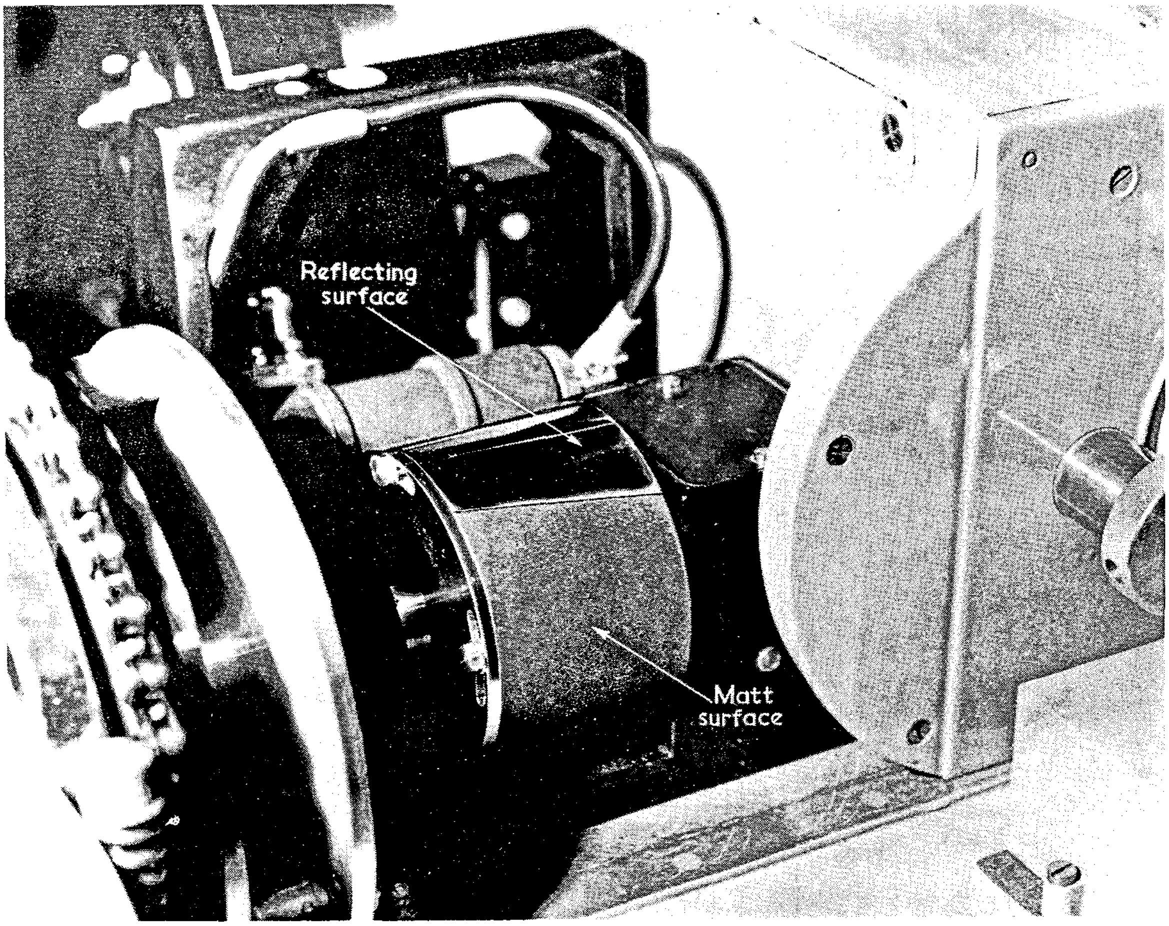

Fig. 2 - Mirror-drum assembly for television frame suppression

Mounted axially on the shaft which drives the camera pulldown mechanism is a segmented cylinder (Fig. 2). The surface of one of the segments is highly reflecting and the other is matt black. A beam of light impinges upon the surface of the cylinder and is either reflected into a photocell or absorbed, according to the angular position of the camera shaft. In this way an electric pulse is generated which causes the display cathode-ray tube to be extinguished whilst the film is being pulled down through the gate, the cylinder having been correctly located on the shaft. It will be seen from the illustration that the divisions between the two segments of the cylinder are not parallel to the axis of the camera shaft and by axial movement of the light source and photocell it is possible to adjust the duration of the blackout pulse until the period of exposure is precisely equal to that of one television frame. For the sake of simplicity the cameras are synchronously driven from the mains, and as the television picture is also locked to the mains, the camera mechanism can be brought into the correct phase simply by rotating the body of the driving motor. The steering wheel, which is prominent in Fig. 1, is mechanically linked to the motor body, and the operator turns this wheel until the "splice" is moved out of the visible picture.

3.4. Camera Mechanism.

The combined camera is basically a standard 35 mm Newall mechanism together with a B.A.F. sound camera, (Fig. 3) all mounted as a complete unit on a single casting. The mechanism performs very satisfactorily on continuous 1000 ft runs provided it is carefully cleaned before reloading, and to facilitate this, a supply of compressed air is made available. The time taken by a skilled operator to clean and reload the maching is approximately 3½ min, so that the 1000 ft film magazines are more than adequate for continuous recording. Some indication of the reliability of the apparatus is given by the fact that during the period in which it was operated by Research Department, 200 000 ft of film was exposed without breakdown of any kind.

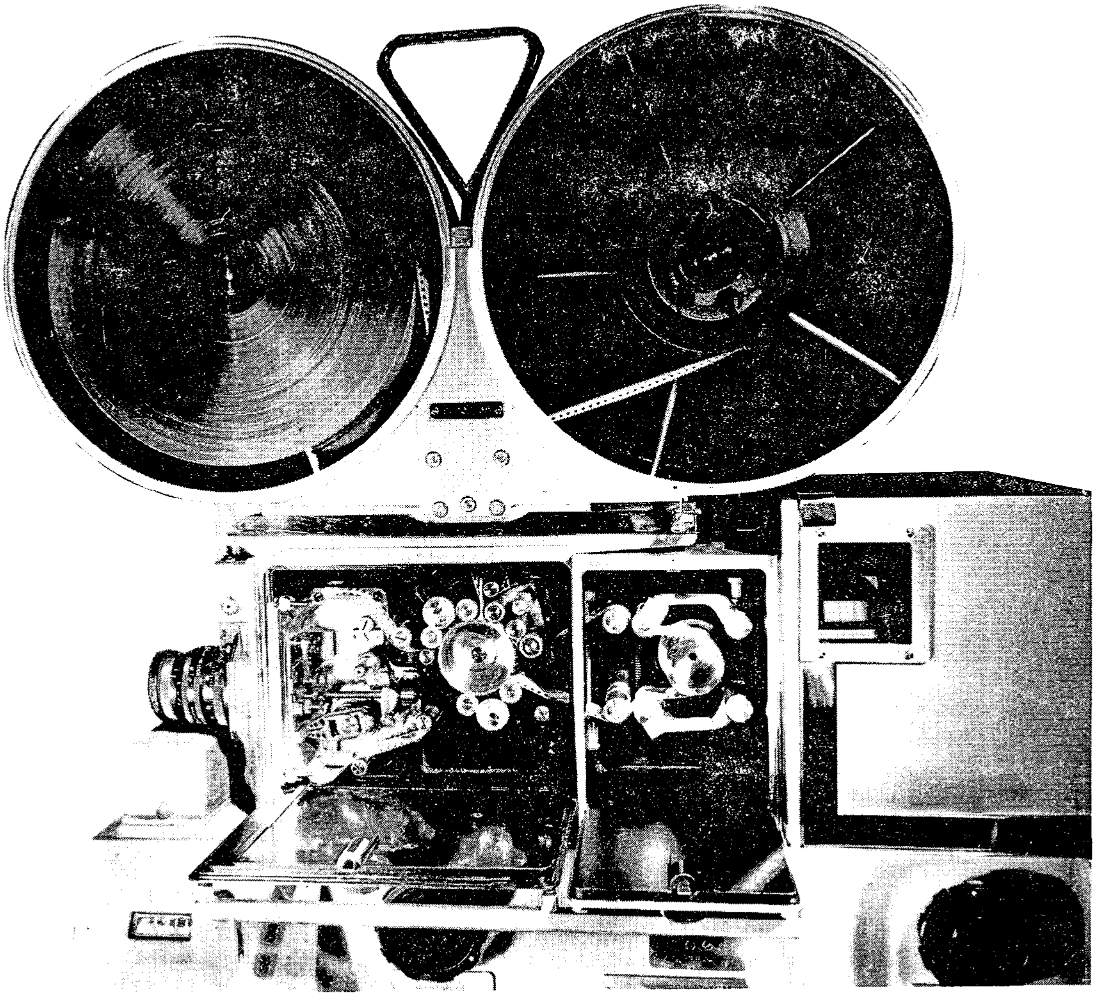

Fig. 3 - Camera unit

3.5. Specification of the Lens.

An advantage of the suppressed-frame system is that the optical arrangements are straightforward and therefore can be extremely efficient. Since the working conditions of the lens are fixed, that is to say, the conjugate foci and the spectral distribution of the incident light are precisely known, it is possible for the lens to have a much higher performance than a normal cinematograph camera lens. Fig. 4 shows the comparison between a lens specially computed by Taylor, Taylor and Hobson Ltd. for the suppressed-frame equipment, and general-purpose lenses[1, 3]. This special lens has a relative attenuation at 3 Mc/s for axial objects of barely 0·1 dB when used at its full aperture of T.2 (f/1·85). The ability to use such a high-performance lens is a great advantage since it permits a lower beam current in the cathode-ray tube, and reduces losses of resolution which can only be partly restored by the use of equalisation.

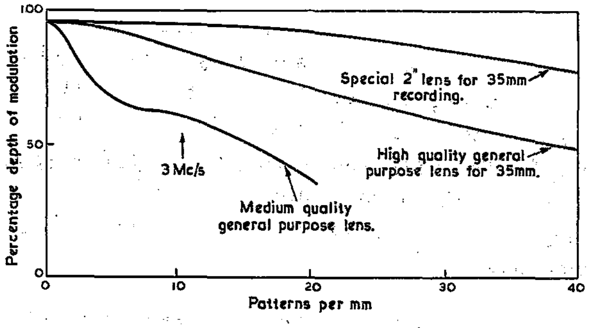

Fig. 4 - Lens performance
Percentage modulation/patterns per mm f/2 anastigmat lenses

3.6. Photometry.

Facilities are provided which enable accurate exposure of the film to be maintained by continuous monitoring of the light incident to the camera. This is achieved by the use of a multiplier photocell mounted directly below the lens and so positioned that it receives light from all parts of the cathode-ray-tube display. The output of the photocell is displayed as a time function on a normal oscilloscope and gives a clear indication of the luminance and contrast range of the display. To provide a standard luminance for calibration purposes, a spot photometer, colour matched to that of the fluorescence of the tube, is also provided, which takes the form of a pistol-shaped projector with a ¼ in. circular screen. The photometer is held in the hand with the small circular screen close to the face of the tube, and the tube beam current is then adjusted to give an accurate match between the light emitted by the phosphor and that reflected from the circular screen.

PART II: THE VIDEO CONTROL EQUIPMENT

1. INTRODUCTION.

Part I of this report describes apparatus by which a television picture, displayed at the screen of a cathode-ray tube, is photographed by means of a suitably mechanised camera. Such a process introduces various forms of distortion, some of which may be corrected by operating upon the television signal before it is applied to the cathode-ray tube.

Those distortions which may be thus compensated can be divided into two main classes, namely:

i. Aperture losses
ii. Modification of the overall contrast law.

The aperture losses manifest themselves as a degradation of the recorded image sharpness and are caused by imperfections in the performance of the display cathode-ray tube, the optical system and the film itself. The overall effect can be expressed as a modification of the equivalent frequency response of the recording system and takes the form of a loss at the higher frequencies. Such a loss, when due to symmetrical apertures, is not accompanied by phase distortion and it is necessary, therefore, to correct such losses by means of an equaliser which does not influence phase.

The overall amplitude characteristic of a television recording and play-back system should not, under normal circumstances, modify the contrast law of the reproduced images and therefore the overall signal gain from the input of the recording

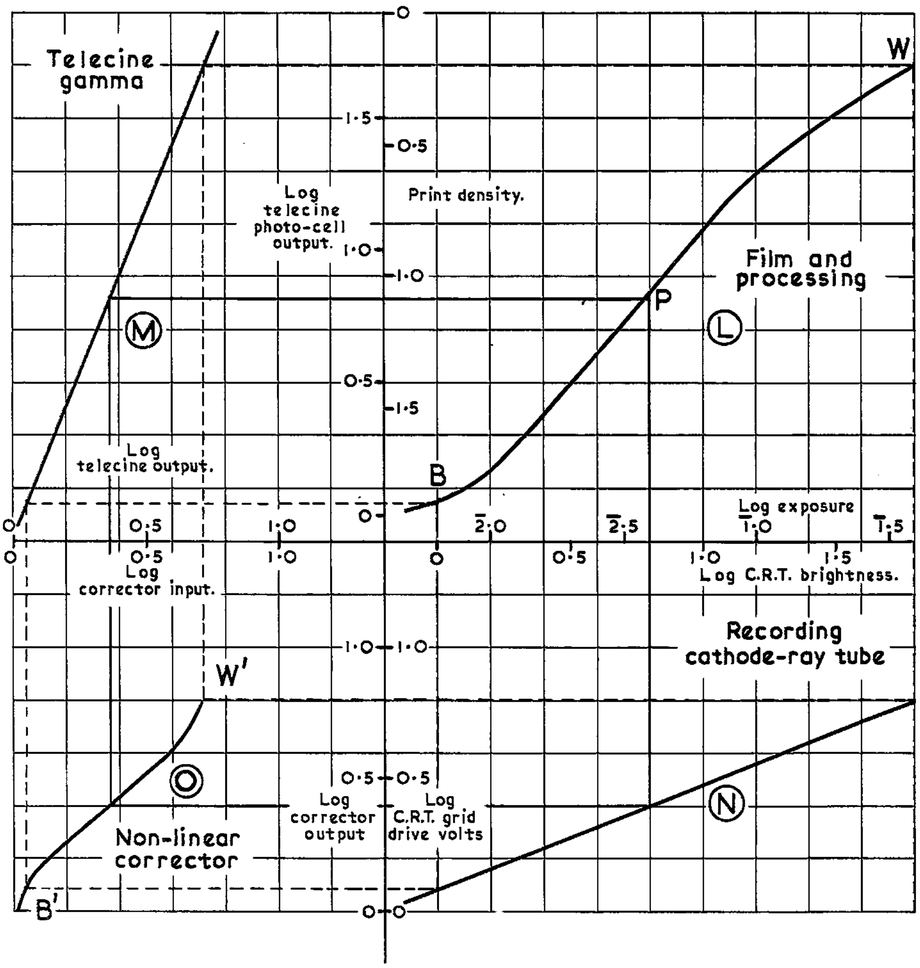

Fig. 5 - A graphical method of calculating the film correction characteristic

equipment to the output of the play-back apparatus should be independent of the signal amplitude.

Without some form of correction, this result could be achieved only over a relatively small contrast range, owing to the shape of the density/log exposure characteristic of typical film. Curve L of Fig. 5 shows a typical contrast characteristic describing the performance of the negative/positive film process.

By the use of a non-linear amplifier in the signal chain, the usable range of the contrast characteristic may be increased appreciably.

Fig. 5, as a whole, illustrates a well known graphical construction whereby the amplitude characteristic of such a corrector may be deduced. In order to describe the diagram it is convenient to assume that BW represents that range of the film characteristic occupied by the recording, the point B representing black level. A point P on the characteristic corresponds to a certain negative exposure and print density. As the print density and the logarithm of the telecine photo-cell output are linearly related, the range BW in curve L may be transferred to a characteristic M representing the logarithm of the telecine signal output in terms of the logarithm of the photo-cell output. In the diagram it has been assumed that these parameters are connected by a power law of exponent 0·4.

By a similar argument, it will be appreciated that the range BW of the curve L can be transformed, via the recording cathode-ray-tube characteristic N, to a range of electrical output from the corrector.

If the corrector input and telecine output signals are to be related linearly, (i.e. a distortionless recording system) the range BW transformed via curve M must be related to the same range transformed via curve N by the required corrector characteristic O. This characteristic expresses the logarithm of the corrector output as a function of the logarithm of its input and shows an increased slope at the extremities of the range $B'W'$.

The desired increase of tone separation in the darker tones and high-lights of the picture is achieved by applying increased amplification to the signal waveform in regions near to those corresponding to black and white respectively.

In addition to those distortions which have been discussed and which are of a fixed nature, others may arise due to differences in the characteristics of picture sources, in particular cameras which may differ, both in contrast law or "gamma" and in definition.

It can be argued, therefore, that, in order to obtain greater uniformity of recording, a variable non-linear amplifier and a variable equaliser should be inserted in the video circuit to the recording apparatus.

Correction of the input signal will, in general, result in a reduction of the signal-to-noise ratio and the degree to which such correction may be applied will, therefore, depend upon the signal-to-noise ratio at the corrector input and the further degradation introduced by the recording/playback process.

Summarising the above discussion, it can be seen that two principal items are required in the signal chain from the equipment input to the recording display unit. The primary function of correction for the photographic process is carried out in a film compensation unit which takes its input from a picture correction unit performing the function of signal standardisation.

5. DESCRIPTION OF THE APPARATUS.

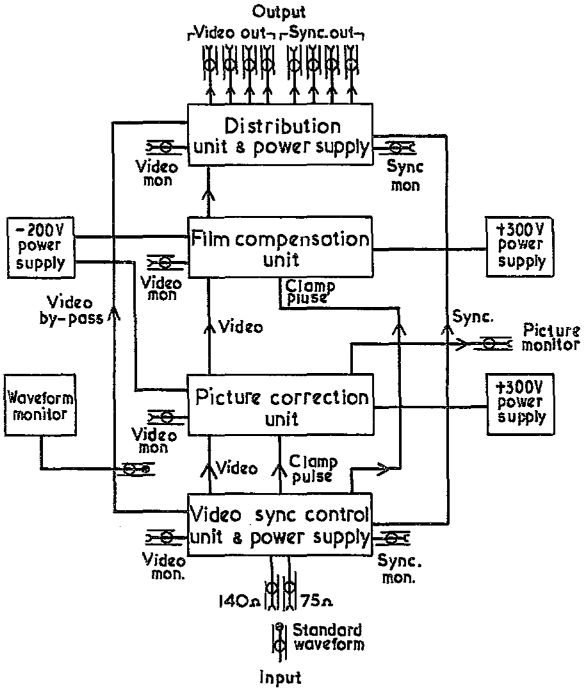

Fig. 6 - Video control equipment

The principles discussed here have been embodied in video control equipment developed for use with the suppressed-frame recording cameras, and Fig. 6 shows a schematic diagram of this apparatus. From the diagram it will be seen that the equipment includes several items in addition to the picture correction and film compensation units. These ancillaries consist of a waveform monitor, a picture monitor, a video/sync. control unit and a distribution unit.

5.1. The Video/Sync. Control Unit.

The deliberate amplitude non-linearity of the amplifiers in both the picture correction and film compensation units is such that signal voltages near black level may be subjected to a greater degree of amplification as compared with the remainder of the voltage range. In order to avoid unnecessarily large signal voltages, and consequently the use of high-dissipation valves in certain circuit positions, it is advisable to remove substantially the synchronising pulse train from the incoming signal before its application to the picture correction and film compensation units. The synchronising pulse train is, however, required for locking the recording display-unit time bases and therefore a similar pulse train is derived from the signal waveform before the modification is effected.

A further train of pulses is required for operating clamp switching circuits at points within the picture-correction and film-compensation units. These switching pulses, having time coincidence with black level intervals of the picture waveform, are derived, in turn, from the synchronising pulses.

All the above preparatory operations are carried out in the video/sync. control unit which provides separate outputs of the modified waveform, the separated synchronising pulses and the clamp switching pulses. The modified video signal output is then passed to the picture correction unit.

5.2. The Picture Correction Unit.

The purpose of this unit is to compensate as far as possible for deficienties in the incoming signal. The criterion for its adjustment is that a monitor connected directly to the output of the unit should produce the best possible picture quality.

The first corrections performed by the unit are those concerned with attenuation and phase distortion of the higher frequency components of the video picture signal. These are performed by an adjustable derivative equaliser utilising the principle[4] whereby one or more time derivatives of the picture waveform are generated and added to the signal itself. By adding a sufficient number of derivatives and by adjusting the amplitude and polarity of each independently, any form of low-pass characteristic may be equalised without introducing any phase distortion requiring further correction. In the case of the derivative equaliser section of the picture correction unit, only the first and second derivatives are generated, which offers a satisfactory compromise between accuracy of correction and ease of adjustment.

The picture tone-gradation is corrected by a variable "gamma" corrector wherein the signal is passed through networks containing non-linear elements in the form of germanium crystal diodes. Control of gradation is thus provided by varying the relative gain of the circuit at different signal magnitudes.

The input to the non-linear amplifier must contain the full direct current component and it is therefore necessary to stabilise the voltage representing black level at a fixed value. This is effected by a well known switching arrangement keyed by a train of clamping pulses from the video/sync. control unit. The non-linear amplifier consists of a modified form of a circuit described elsewhere[5].

Two video signal outputs are provided from the picture correction unit; the first is fed to a good quality picture monitor used for picture assessment, and the second passes the signal to the film compensation unit.

5.3. The Film Compensation Unit.

At the input of this unit the signal is assumed to have been corrected as closely as considerations of signal-to-noise ratio allow, so as to conform to standard characteristics. As pointed out in the introduction, the film compensation unit should have a transfer characteristic which approximates to the inverse of that introduced by the recording process. Most of the aperture losses in the recording process occur at points such as the screen of the recording cathode-ray tube and the optical system of the film camera, that is, at places where the signal has a "gamma" of unity. It can be shown that it is preferable to equalise such losses by pre-emphasising the signal voltage at a point in the circuit of the film compensation unit where the "gamma" is also unity.

Fig. 7 shows a schematic diagram illustrating the sequence of the various processes carried out within the unit. As will be seen, the incoming signal is fed to a circuit having a 2·5 power law from which a unity-"gamma" signal results, and the pre-emphasis for correcting subsequent aperture losses is now achieved by a similar derivative equaliser to that contained in the picture correction unit.

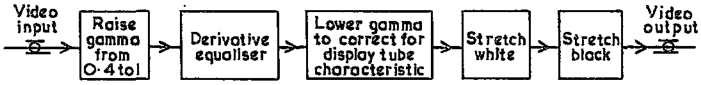
Video input
Raise gamma from 0·4 to 1
Derivative equaliser
Lower gamma to correct for display tube characteristic
Stretch white
Stretch black
Video output

Fig. 7 - Film compensation unit

After the pre-equalisation it is necessary first to restore the contrast law of the signal to a value approximating to the reciprocal of that of the recording cathode-ray tube. Secondly distortion of the contrast law caused by the photographic process takes the form of inadequate amplification of the black and white portions of the signal range, and therefore in order to compensate, increased amplification is provided for both these regions ("stretch white" and "stretch black", shown in Fig. 7).

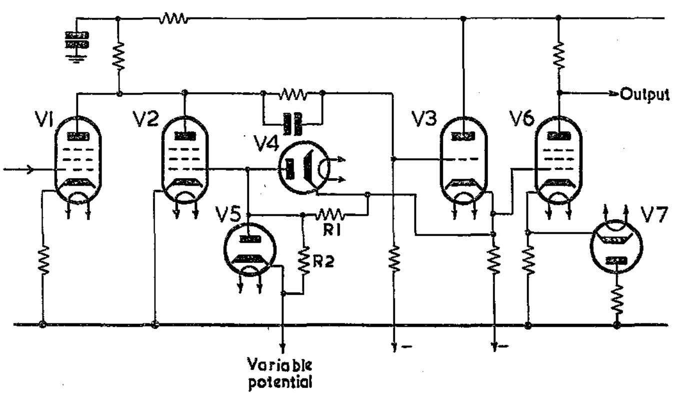

Fig. 8 - A circuit suitable for the correction of non-linear distortion in television recording

The basic circuit arrangement used to perform the above three operations is shown in Fig. 8. The design is based upon a circuit[6] developed for film-scanner use. The input signal, having a polarity such that white corresponds to the maximum negative voltage excursion and including the full d.c. component, is applied to the valve V1, whose anode circuit is common to that of V2. This circuit is directly coupled to V3, a cathode follower, which in turn drives V2 via the network V4, V5, R1 and R2. Assuming, for the moment, that V4 presents an impedance which is low compared with either R1 or R2, and that V5 is cut off, it will be seen that a negative feedback path exists between the anode and grid of V2. The (I_a, V_a) characteristic of V2 has a bottom-bend curvature of which a certain portion corresponds to a "high gamma". Due to this "high-gamma" element in the feedback path, the overall transfer characteristic from the grid of V1 to the cathode of V3 will have a "low gamma" which can be arranged to approximate to a value of 0·4. The signal voltage at the cathode of V3 has a polarity such that the maximum positive excursion corresponds to white, and when this potential exceeds a certain value, the feedback voltage at the grid of V2 is attenuated by cut-off of V4 and the conduction of V5. Those voltages corresponding to the white and near-white tones of the picture are arranged to exceed this critical value and therefore undergo increased amplification. The resistors R1 and R2 control the maximum changes of series and shunt impedance in the feedback path and thereby control the amount by which the amplification is varied.

The signal at the cathode of V3 is passed to V6, the cathode circuit of which contains the non-linear element V7. Above a certain grid voltage the diode V7 is cut off and V6 suffers degenerative feedback due to a high cathode resistance. Below this voltage V7 conducts and the gain of V6 increases. By this means those voltages corresponding to the near-black tones of the picture are subjected to greater amplification than those corresponding to mid-tones. The curvature of the (I_a, V_a) characteristic of V4, V5 and V7 permits the changes in amplification to take place without discontinuity.

The overall amplitude characteristic of the circuit shown can be adjusted to approximate the converse of that due to the display cathode-ray tube together with the film.

5.4. Distribution Unit.

Fig. 6 shows that the signal output from the film compensation unit is fed to a distribution unit from which identical outputs are available for the recording display units. The distribution unit also provides several outputs of the synchronising pulse train derived in the video/sync. control unit.

6. OPERATING ASPECTS.

The apparatus illustrated in Fig. 6 incorporates facilities whereby an alternative path may be provided from the video output of the video/sync. control unit to the relevant input of the distribution unit. By this means recording of a programme may continue, with substandard performance, in spite of breakdown in either the picture correction or film compensation units.

Further protection is afforded by duplicating the video/sync.-control and distribution units and means are available for a rapid changeover from one unit to another which is identical in performance.

A complete account of the whole equipment, together with detailed circuit information, is provided in Section 3 of the Research Department Handbook, entitled "Experimental Suppressed Frame Television Recording Channel".

7. A POSSIBLE FURTHER DEVELOPMENT.

All previous considerations have assumed that the image displayed and recorded is of the positive form and that the film process incorporates a negative from which, in turn, a positive print is taken. It may be advantageous, in certain circumstances, to record the image directly on to the positive film, which implies that an electrical analogue of one photographic process be incorporated in the video equipment.

The characteristics required may be derived as follows:

Over that part of the film characteristic where "gamma" is constant we may write

$$D = \gamma \log E + K \qquad (1)$$

where D represents film density, E the exposure, and K is a constant.

Also

$$D = \log \frac{1}{T} \tag{2}$$

where T denotes the transmission coefficient of the processed film and therefore represents the voltage obtained from the playback photocell.

From (1) and (2)

$$\log \frac{1}{T} = \gamma \log E + K$$

Hence

$$T = \frac{1}{C.E^{\gamma}} \tag{3}$$

where $\log C = K$.

The electrical arrangement required to perform the operation described by equation 3 must incorporate a circuit whose output voltage bears a reciprocal relationship to the input, and when "γ" has a value other than unity additional non-linear amplification must be incorporated before or after the reciprocal process.

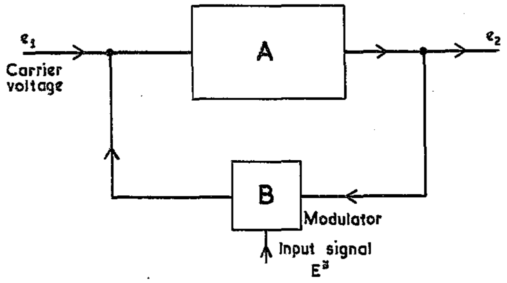

Fig. 9 - Method of taking the reciprocal of a signal

One circuit arrangement proposed for performing the reciprocal operation is based upon the use of logarithmic and anti-logarithmic amplifiers[7]. Another possible approach is illustrated in Fig. 9. This consists of an amplifier A (of gain μ) and modulator B (of gain β) in the feedback path. If a carrier voltage e_1 is injected as shown, then the gain of the circuit may be expressed by the well known relationship

$$\frac{e_2}{e_1} = \frac{\mu}{1-\mu\beta} \tag{4}$$

If the gain of the modulator B is varied according to an input E^{γ} such that

$$\beta = \beta_0 \, . \, E^{\gamma} \tag{5}$$

then from (4) and (5)

$$\frac{e_2}{e_1} = \frac{\mu}{1-\mu\beta_0 \, . \, E^{\gamma}}$$

If for all values of E^{γ}, $\mu\beta_0 \, . \, E^{\gamma} \gg 1$ and the feedback is of suitable polarity, then

$$e_2 = -\frac{e_1}{\beta_0 E^{\gamma}}$$

$$= \frac{-1}{(\beta_0/e_1) \, . \, E^{\gamma}} \tag{6}$$